ISSN 0021-3640, JETP Letters, 2018, Vol. 108, No. 2, pp. 132–136. © Pleiades Publishing, Inc., 2018.
Original Russian Text © M.V. Eremin, D.S. Kochergin, 2018, published in Pis'ma v Zhurnal Eksperimental'noi i Teoreticheskoi Fiziki, 2018, Vol. 108, No. 2, pp. 119–123.

CONDENSED MATTER

On the Theory of Plasmon Dispersion in Electron-Doped Cuprates

M. V. Eremin[a], * and D. S. Kochergin[a]

[a] *Institute of Physics, Kazan Federal University, Kazan, 420008 Russia*

**e-mail: meremin@kpfu.ru*

Received May 22, 2018; in final form, June 21, 2018

An explicit expression for the dynamic charge susceptibility for electron-doped cuprates has been derived. This expression accurately reproduces the wave vector dependence of the plasmon frequency observed in inelastic X-ray scattering experiments for $Nd_{2-x}Ce_xCuO_4$. The imaginary part of the charge susceptibility along the triangular path in the Brillouin zone is plotted. It is demonstrated that the spectral weight of the plasmon mode near $q = 0$ is negligibly low. The calculated frequencies of the plasmon mode for all wave vectors in the Brillouin zone turn out to lie outside the range of damping related to electron–hole excitations. A formula for the charge susceptibility is derived within the t–t'–t''–J model supplemented by the Coulomb interaction operator and three-site terms. The derivation is performed by the Green's function technique employing the formalism of composite Hubbard operators and the Mori projection method, which have proved themselves in the analysis of collective spin excitations. The used Fourier transform of the Coulomb interaction corresponds to the monolayer model with a spatially periodic structure, which is embedded in a three-dimensional crystal lattice.

DOI: 10.1134/S0021364018140059

The recent experimental studies of the nature of high-T_c superconductivity are mainly focused on the determination of the spectra of collective excitations. For this aim, in addition to the magnetic resonance and inelastic neutron scattering techniques, which probe the magnetic susceptibilities at small and large wave vectors, respectively, the resonant inelastic X-ray scattering (RIXS) method is actively developed to determine the spectral dispersion of collective excitations at intermediate wave vectors. Thus, in combination with neutron scattering, RIXS allows one to determine the dispersion of collective excitations within the whole Brillouin zone. This information is quite important and makes it possible to qualitatively determine the efficiency of a particular pairing mechanism for charge carriers. The most actively discussed pairing mechanisms for cuprates are the plasmon [1–3], superexchange [4], phonon [5], and spin-fluctuation [6, 7] mechanisms. The last mechanism becomes preferable as the dominant mechanism in cuprates. However, the ongoing experimental studies pose new questions. In particular, the asymmetry of collective excitation spectra in electron- and hole-doped cuprates [8, 9] observed by RIXS in 2014 has naturally attracted special attention. In general, the frequencies of collective excitations in electron-doped cuprates turn out to be higher than those in hole-doped cuprates. As pointed out in [7], this is quite surprising within the spin-fluctuation pairing mechanism because the superconducting critical temperature in electron-doped cuprates is far below that in the hole-doped ones. Moreover, a drastic difference was revealed in the behavior of collective charge excitations (plasmons). In hole-doped cuprates ($YBa_2Cu_3O_7$), the plasmon frequency is about 0.8 eV [10, 11] and its dispersion can in general be described in the usual random phase approximation [12]. However, as became clear later, the random phase approximation is hardly applicable for the description of the high-frequency part of spin excitations probed by inelastic neutron scattering [13]. This fact becomes especially evident from the analysis of RIXS data.

The mode found by RIXS in $Nd_{2-x}Ce_xCuO_4$ exhibits an unusual dispersion law [8, 9]. At small q, the frequencies are equal to about 0.3 eV and grow with the wave vector up to 1 eV at $q_x = 0.3\pi$ and larger. This new mode cannot be attributed to spin excitations (which are also observed) and can be probably interpreted in terms of plasmons. To support this conjecture, the authors of [9] numerically calculated the imaginary part of the charge susceptibility for a 20-particle cluster with the t–t'–t''–J model Hamiltonian [9] supplemented by three-particle correlations. The calculated peak positions of the imaginary part of the ac charge susceptibility at high frequencies correlate well with the experimental data. However, the Coulomb interaction of charge carriers was disregarded for